# Studies on Mechanical Behaviour of Knitted Glass-Epoxy Composites

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ABSTRACT: Resin Transfer Molded (RTM) laminates from weft rib knit glass preforms with added reinforcements were developed using closed mould vacuum resin suction technique. In all, six types of preforms (with additional reinforcements in the course direction) were obtained using a flat bed hand-knitting machine. The laminate fibre weight fractions ranged from 0.37 to 0.67 and their tensile and flexural properties were evaluated. Test results indicated that strengths higher than those of the woven fabric composites could be achieved in the course direction with unique failure modes occurring differently from those of the latter.

KEY WORDS: knit preforms, woven fabrics, reinforcements, RTM laminates.

## INTRODUCTION

IN ITS MODERN sense, the advanced composite is not only the one made of high stiffness fibres, but also of higher fractured toughness matrices. Even more important is the capability of the composite to retain the room temperature properties at elevated/service temperature limits, including the impact conditions. This has led to the concept of high performance composite structures, which today mean structures with long-term property retention on one side and those with least tendency of delamination on the other. This clearly calls for exploration on new configurations such as knits, braids and 3D woven preforms. Of these, knits have taken a unique slot due to their versatility of manufacture (single stage viz., yarn to preform). In-

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vestigations on diverse areas of knits such as studies on the mechanical behaviour by Fujita et al. [1], improvements in impact strength by Chou et al. [2], tensile failure mechanisms and tensile properties characterisation by Ramakrishna et al. [3] and designing of knitted preforms by Lu et al. [4] have been carried out. The effects of added reinforcement (in course direction) on mechanical properties of composites have however not been reported. The present work addresses this issue with reference to a knit glass-epoxy composite with varied reinforcement content.

## EXPERIMENTAL

Regular 1 × 1 rib knit preforms were developed on a 5″ gauge flat bed hand-knitting machine. Two 300 Tex E-glass strands were used in the feeder eye of the knitting machine for loop formation. Reinforcements were introduced in the course direction between each row of loops. The reinforcements were formed separately by utilising the 300 Tex strands. One base preform without any course direction reinforcement was used for comparison (termed as plain knit). The other preforms comprised of reinforcements of 1800, 3600, 5400, 7200, and 9000 Tex E-glass yarns in the course direction. Thus in all, six types of preforms were developed. Figure 1 gives a representative sketch of the reinforcement insertion.

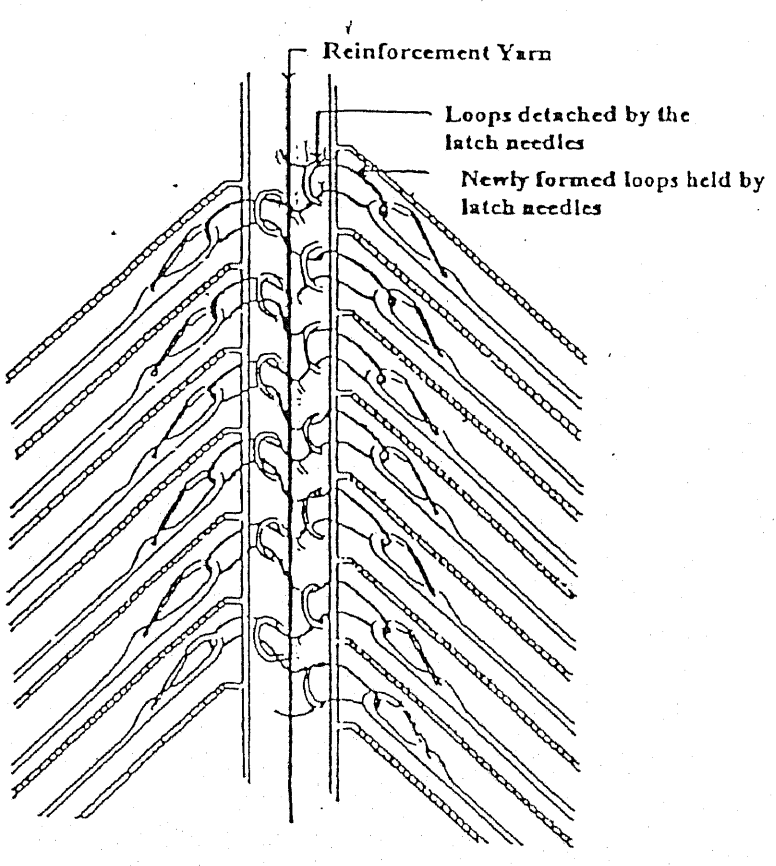


*Figure 1. A schematic of the reinforcement insertion in the knit.*

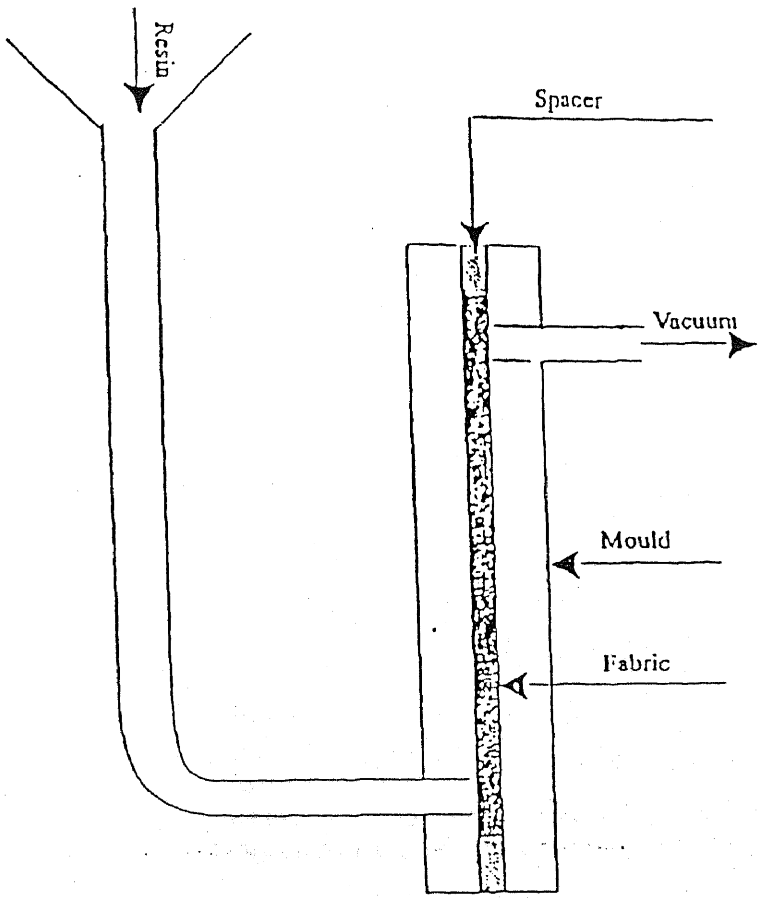


*Figure 2. Experimental RTM set-up used.*

Composite laminates (225 mm × 225 mm) were prepared from these six preforms using an RTM concept and Figure 2 shows the schematic of the experimental set-up. A bi-functional epoxy resin system has been used in the fabrication of these laminates. Step post-cured laminates (50°C/70°C/85°C) were tested for tensile and flexural properties in accordance with ASTM D 3039 and C 393 respectively.

## TEST RESULTS AND DISCUSSIONS

Figure 3 shows the variation of fibre weight fraction as a function of increased reinforcement in the course direction. Figure 4 shows the fabric and laminate thickness for these materials. It can be noted that the laminate thickness is held constant to ensure variability of fibre content.

From Figure 5, it can be seen that the tensile strength properties in the reinforcement direction are comparable with the strengths of bi-directional woven when 5400 Tex yarn is used as reinforcement. Beyond this viz., 5400 Tex reinforcement, the strengths obtained are higher than the corresponding standard woven fabric composite laminate (viz., a typical 40 kg/mm$^2$ at the standardised 0.65 $W_f$). Figure 6

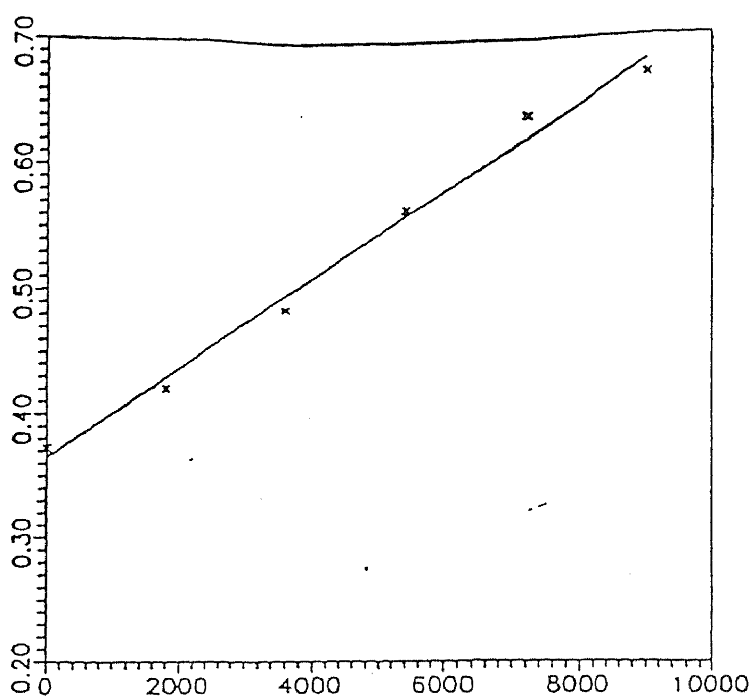


*Figure 3. Effect of additional reinforcements on fibre weight fraction of knit laminates.* x-Axis: *Reinforcements (yarn count in Tex). y-Axis: Fibre weight fraction.*

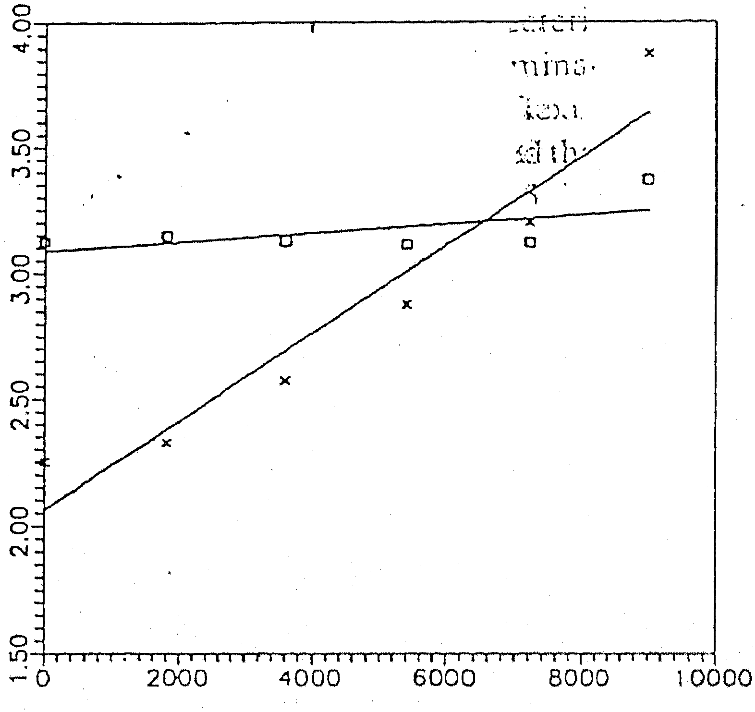


*Figure 4. Effect of additional reinforcements on fabric and laminate thickness. x-Axis:* Reinforcements *(yarn count in Tex). y-Axis: Thickness in $m^{-3}$. □ laminate, × fabric.*

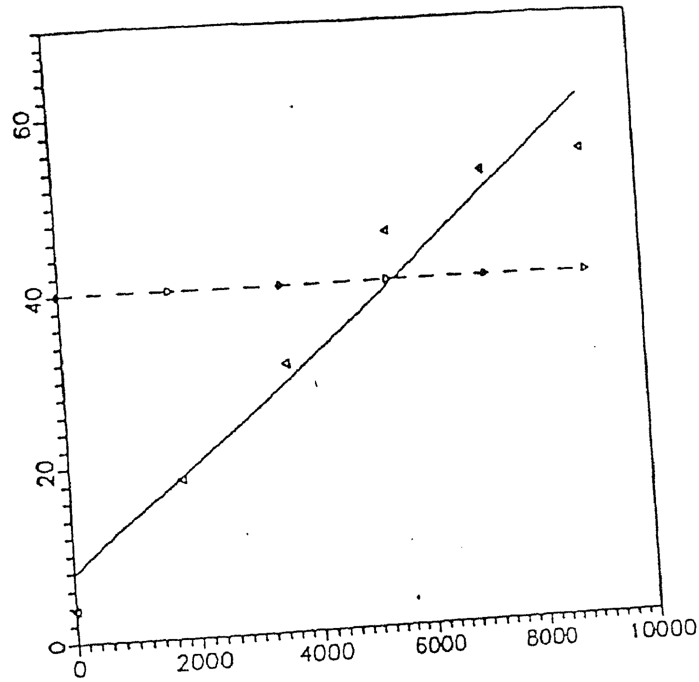


*Figure 5. Variation of tensile strength of different knit laminates. x-Axis: Reinforcements (yarn count in Tex). y-Axis: Strength in Kg/mm². (----: Indicates corresponding strength of woven fabric composite.)*

shows the photographs of the actual failure modes for the tensile test coupons. It can be observed that there is a longitudinal splitting in the reinforcement direction but without fibre bushing (characteristic of U.D. laminates) obviously due to the loop effects. The question of delamination akin to woven fabric composites doesn't arise here. Figure 7 indicates the flexural test results of these laminates in the course direction. It can further be noted that a knit fabric laminate of 6000 Tex reinforcement matches the strength of a 0.65 $W_f$ woven fabric laminate. Thus, the tensile and flexural properties equivalent to those of woven fabric composites can be realised from weft rib knit preforms with reinforcing inlays of 5400–6000 Tex range in the course direction.

Referring to Figures 3, 5 and 7, a linear relationship has been found to exist between the material property and the reinforcement content in the course direction viz., Tex count and is as given below:

$$W_f = 0.000035\ (\text{Tex Count}) + 0.3649 \rightarrow \tag{1}$$

$$\sigma_{ts} = 0.003719\ (\text{Tex Count}) + 9.9162 \rightarrow \tag{2}$$

$$\sigma_{flx} = 0.005861\ (\text{Tex Count}) + 7.7891 \rightarrow \tag{3}$$

where $W_f$ is fibre weight fraction, $\sigma_{ts}$ is laminate tensile strength and $\sigma_{flx}$ is laminate flexural strength.

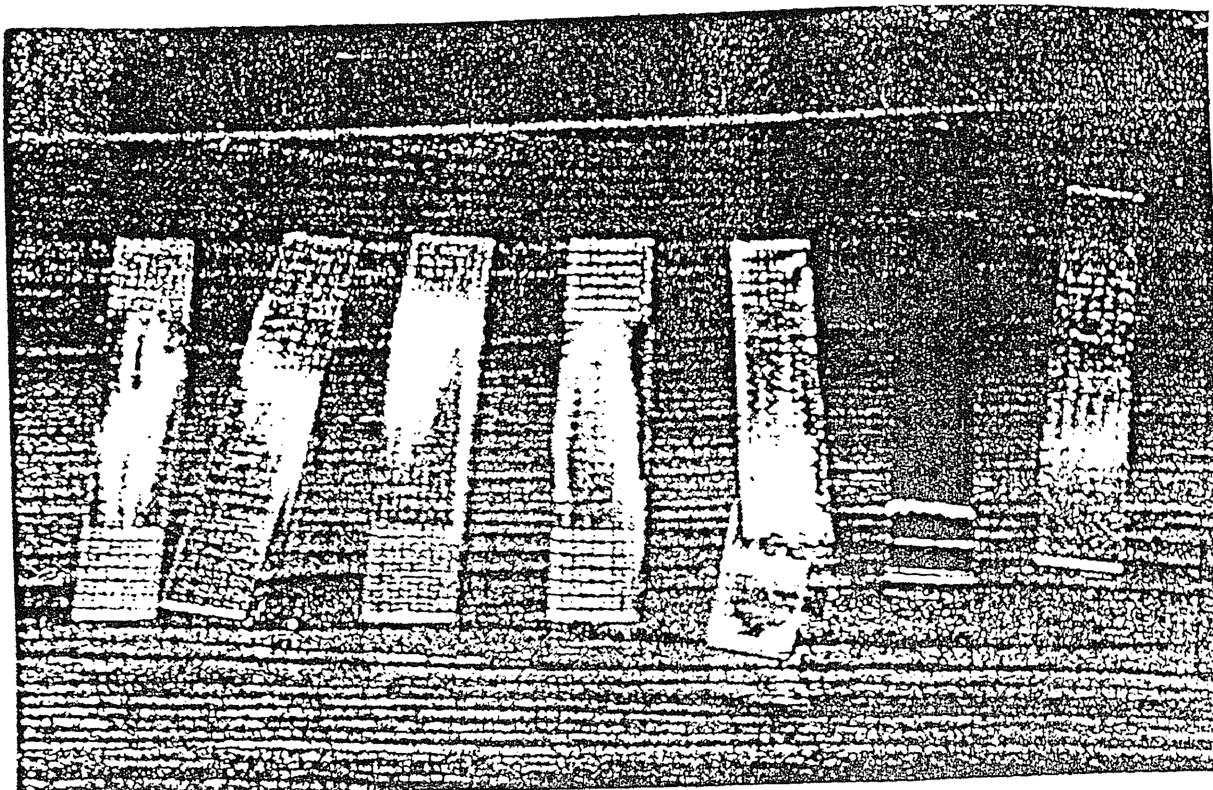

Figure 6. A photographic view of failure modes of tensile test coupons. (From left to right): 7200, 3600, 5400, 9000, 7200, plain and 1800 Tex reinforced rib knit tensile tested coupons.

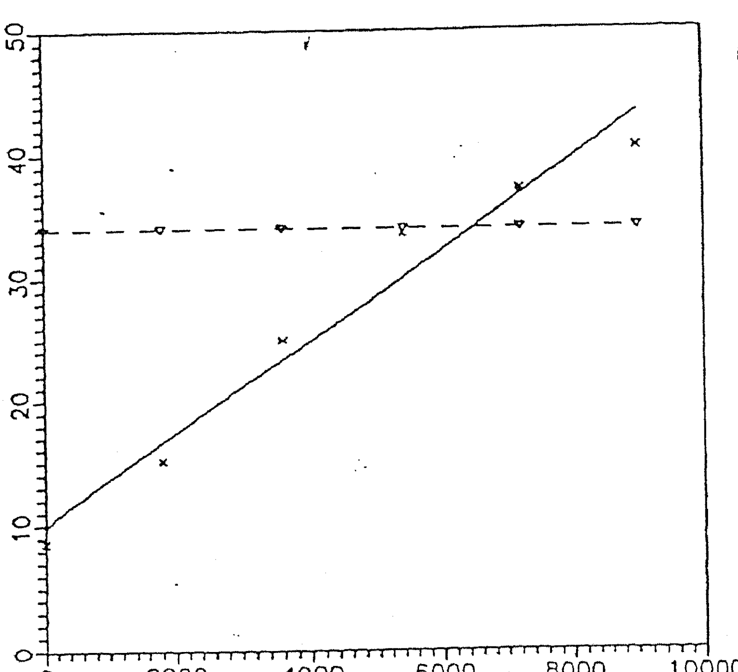


Figure 7. Variation of flexural strengths of different knit laminates. x-Axis: Reinforcements (yarn count in Tex). y-Axis: Strength in Kg/mm$^2$. (——: Indicates corresponding strength of woven fabric composite.)

Note: In all the plots, plain knit values have been assigned at 0-point on the $x$-axis, as there is no additional reinforcement in the course direction for the same. The transverse properties in the case of tensile and flexural can be expected to be equivalent to those obtainable in the uni-directional fabrics.

## CONCLUSIONS

Weft rib knit preforms with enhanced strength properties can act as a supplement for uni-directional woven fabric composites presently being used, without the risk of delamination or fibre bushing.

Additional reinforcement in the course direction substantially increases the strength properties of the composites as compared to the original preform, i.e., without any reinforcements (plain knit).

Progressive increase in strength properties has been observed with increase in the yarn count (viz., Tex) of the reinforcement.

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